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TEM Observation of Lattice Image of $Al_xGa_{1-x}As$-AlAs Superlattice with High Contrast

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High resolution transmission electron microscope (TEM) observation is made on cross sections including the growth direction of superlattice samples with large Al compositional difference. The samples are GaAs-AlAs and $Al_{0.2}Ga_{0.8}As$-AlAs superlattices grown by MBE. Lattice images show high contrast between two different layers, and regular ordering of lattice points without any irregularity at the heterointerfaces. The high contrast allows one to determine the location of the heterointerfaces in an atomic scale, and the abruptness at the heterointerface was found to be one or two monolayers.

1. Introduction

Semiconductor superlattices and heterojunctions have recently gained much attention to electronic and/or optical device application. At the same time, importance has been increased of the characterization of heterointerfaces, and several methods have been developed which include electronic and optical methods. Weisbuch and his coworkers[1] and Goldstein et al.[2] have used a low temperature photoluminescence (PL) method to investigate the abruptness of GaAs-Al(Ga)As heterointerfaces of superlattices grown by molecular beam epitaxy (MBE), and found that the interfaces are abrupt in an atomic scale and do not include so-called alloy clustering. From the linewidth of PL of GaAs-AlAs superlattices, the latter authors suggested that the thickness of the potential-well layer (GaAs layer) fluctuates in the growth plane by one atomic layer, and the lateral dimension of the region within which the thickness is perfectly uniform is the same order as the electron de Broglie wavelength. This fluctuation limits the dynamics of the two dimensional exciton which has potential for application to optical bistable devices and switches.[3]

In order to study more directly the abruptness of the heterointerface, a cross-sectional observation of the constituent lattice arrangement by using a high resolution transmission electron microscope (TEM) is necessary. Petroff studied the structure of a GaAs-AlAs monolayer superlattice[5], and showed a bright field image with a clear contrast separating each of the constituent layers. But unfortunately, it is difficult from this image to obtain some information on the constituent lattice arrangement across the heterointerfaces. Olsen et al.[6] and, more recently, the present authors[4] reported the lattice image observation, and showed that the lattice point arrangement is quite regular across the heterointerfaces. But due to the insufficient contrast between each of the layers, it was difficult to determine the location of the heterointerface and to observe its abruptness.

This paper reports the lattice image observation by TEM of MBE grown GaAs-AlAs and $Al_{0.2}Ga_{0.8}As$-AlAs superlattices. Because of larger difference in composition between the potential-well and barrier layers than previously, a clear contrast is obtained. A discussion on the abruptness at the heterointerface is given.

2. Experimental Results and Discussions

The superlattices consist of undoped GaAs (AlGaAs) wells with thickness L_z and undoped AlAs barrier layers with thickness L_B. Superlattice parameters used in this experiment are shown in Table I. Layer thicknesses were independently determined by measuring AlAs and GaAs growth rates using a shadow mask method,

Table I Layer thicknes and compositions.

Sample No.	
# 1	GaAs(100 Å) - AlAs(60 Å)
# 2	$Al_{0.2}Ga_{0.8}As$(100 Å) - AlAs(25 Å)

and by X-ray double crystal diffraction method.[7] Sample #1 is a binary-binary superlattice and sample #2 is a ternary-binary superlattice. Compositional difference of the potential-well and barrier layers is 1.0 and 0.8 for samples #1 and #2, respectively, which are larger than the previous case(0.28).

Sample preparation for TEM observation is essentially the same as described by Lidbury et al.[8] and is schematically shown in Fig. 1 of Ref. 3. The TEM apparatus used here is a JEM-200CX with 200 kV acceleration voltage. The incident beam is perpendicular to the (110) surface.

Figures 1 and 2 show the lattice images for sample #1 and #2, respectively, which are composed of the direct transmission beam, four (111) equivalent Bragg diffracted beams and two (002) equivalent beams as shown in Fig. 3. The spacings are 3.23 Å for the (111) equivalent planes and 2.8 Å for the (002) equivalent planes as shown in the figures.

Figure 3 shows a transmission electron diffraction (TED) pattern for sample #2. The electron-beam coherent length (150-200 Å) is larger than, or the same order as the periodicity of the superlattice. Thus, the TED pattern exhibits superlattice satellite diffraction spots in the [001] growth direction, in addition to the fundamental diffraction spots. The TED pattern for sample #1 was similar to that for sample #2.

For the lattice image of the GaAs-$Al_{0.28}Ga_{0.72}As$ superlattice, described previously in Ref. 3, some ambiguity in the determination of the location of the heterointerfaces is

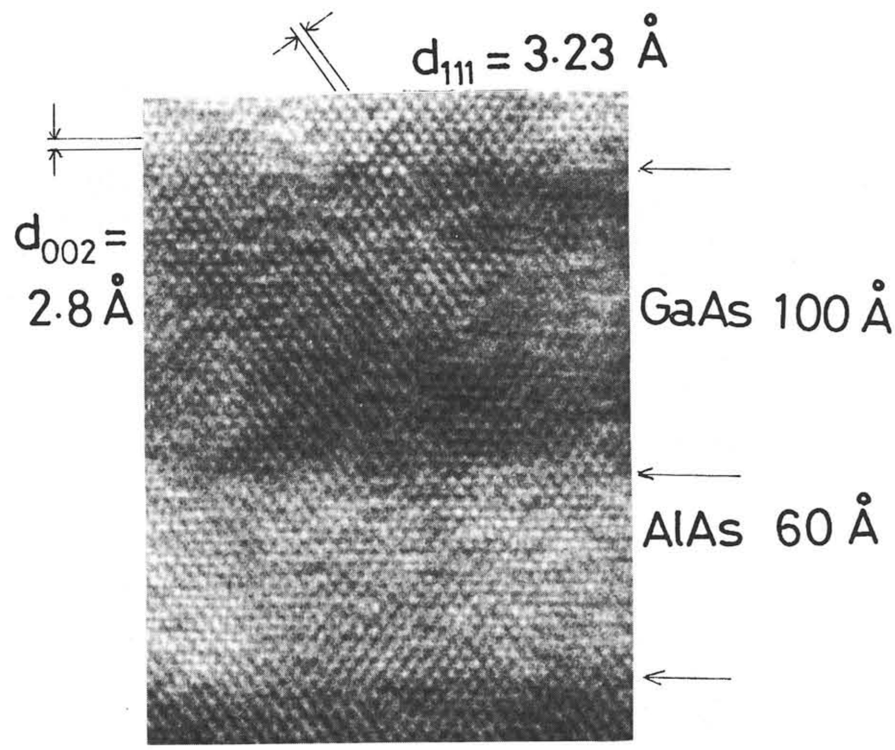

Fig. 1 A lattice image of a GaAs(100 Å)-AlAs(60 Å) superlattice.

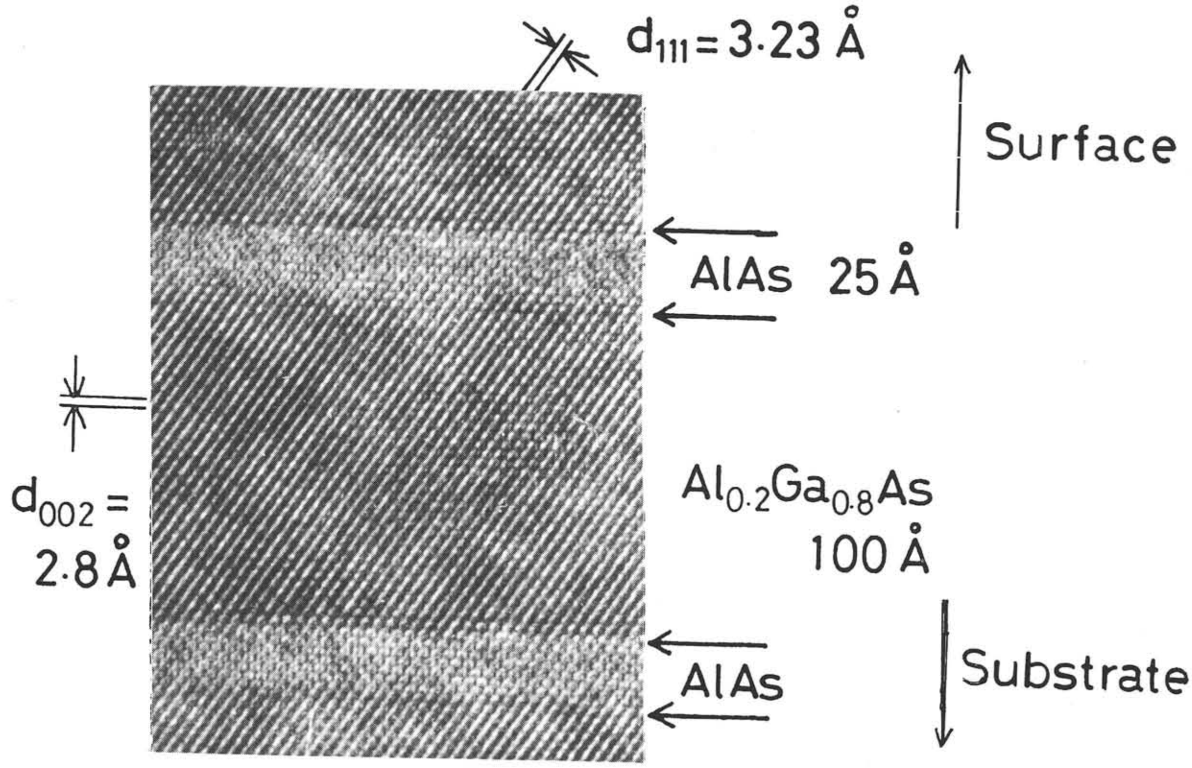

Fig. 2 A lattice image of a $Al_{0.2}Ga_{0.8}As$(100 Å)-AlAs(25 Å) superlattice.

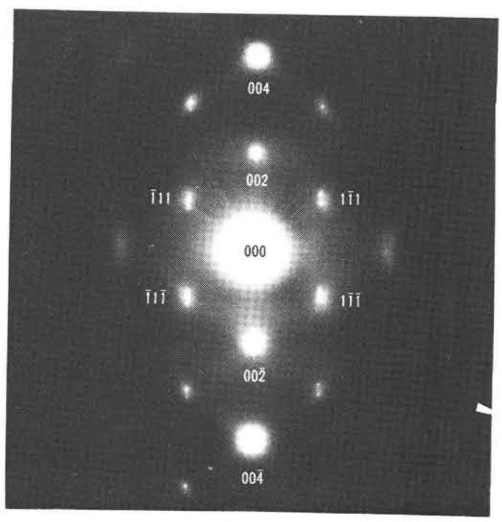

Fig. 3 A transmission electron diffraction (TED) pattern for Sample #2.

included due to low contrast between each layers. One reason for this is considered due to the small difference in composition between the potential-well and barrier layers.

In the present lattice images shown in Figs. 1 and 2 the dark and bright stripes show such a high contrast that the GaAs(AlGaAs) and AlAs layers can be distinguished clearly. Thus, the location of the heterointerfaces can be determined within an atomic layer scale. Figures 1 and 2 indicate that the abruptness at the GaAs(AlGaAs)-AlAs heterointerfaces is one or two monolayers. This abruptness is the same as expected from the low temperature PL study.[1] It is especially worthwhile to note that, as shown in Fig. 2, when the ternary $Al_{0.2}Ga_{0.8}As$ is grown on a binary AlAs, its heterointerface is much more abrupt than that when the binary is grown on the ternary. This result means that AlAs (binary) grown surfaces were smoother than AlGaAs (ternary) grown surfaces. Probably this may be related to the results from the inferior transport in inverted HEMT structure[9], although it is not yet clarified.

3. Conclusion

Using a high resolution transmission electron microscope, MBE grown GaAs(AlGaAs)-AlAs superlattice structures were examined in an atomic scale. The following results were obtained.

(1) Because of larger difference in composition between the potential-well and barrier layers than previously[4], lattice images of GaAs(AlGaAs)-AlAs superlattices exhibited dark and bright stripes with higher contrast between the two different layers.

(2) The abruptness in the heterointerfaces was found to be one or two monolayers.

(3) When the ternary was grown on the binary, its interface was more abrupt than that in the inverse case.

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References

1) L.Goldstein, Y.Horikoshi, S.Tarucha and H.Okamoto: Jpn.J.Appl.Phys., 22 (1983) 1489.

2) C.Weisbuch, R.Dingle, A.C.Gossard and W.Wiegman: J.Vac.Sci.& Technol., 17 (1980) 1128.

3) Y.Masumoto, S.Shionoya, and H.Kawaguchi: Phys.Rev., B29 (1984) 2324.

4) H.Okamoto, M.Seki, Y.Horikoshi: Jpn.J.Appl.Phys., 22 (1983) L367.

5) P.M.Petroff: J.Vac.Sci.&Technol., 14 (1977) 973.

6) A.Olsen, J.C.H.Spence, P.Petroff: Proceeding of Thirty-eighth Anual meeting Electron Microscopy of Society of America (1981) 318.

7) T.Ishibashi, Y.Suzuki and H.Okamoto: Jpn.J.Appl. Phys., 20 (1981) L623.

8) D.P.G.Lidbury, H.R.Petit and G.R.Booker: Electron.Eng., 43 (1971) 50.

9) H.Morkoc, T.J.Drummond, R.E.Throne, and W.Kopp, Jpn.J.Appl.Phys. 20 (1981) L913.